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POWER-BASED RATE ADAPTATION OF WIRELESS COMMUNICATION CHANNELS

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POWER-BASED RATE ADAPTATION OF WIRELESS COMMUNICATION CHANNELS

BACKGROUND OF THE INVENTION

[0001] The present invention generally relates to wireless communication networks, and particularly relates to adaptive rate control of communication channels in such networks.

[0002] Evolving wireless communication networks, such as those based on the IS-2000 family of standards, offer a wide range of services including voice, data (web, email, etc.), and streaming media services. Differing applications and Quality of Service (QoS) requirements result in individual data users having differing data rate needs. IS-2000 networks typically serve individual data users on the forward link using forward link fundamental channels (F-FCHs) that support a maximum channel data rate of 9.6 kpbs. If that data rate is insufficient to meet the service requirements of a particular data user, the network assigns a forward supplemental channel (F-SCH) in conjunction with that user's F-FCH. F-SCHs are configured to have data rates expressed as a multiple of the F-FCH data rate, and thus a data user may be assigned a F-SCH rate of 1x, 2x, 4x, etc., depending on the particular service needs of that user.

[0003] Typically, the assignment of a F-SCH to a particular data user is triggered by an excess data buffer size, i.e., the queue for incoming data to be transmitted to the user is too large, or is triggered by the rate of the incoming data. Selection of a F-SCH initial date rate may be based on the predicted data throughput to the data user, or may be based on other considerations. Regardless, once the F-SCH is assigned, conventional networks either leave the initially configured rate unchanged for the duration of the assignment, or make relatively infrequent rate changes based on, for example, changes in the incoming forward link traffic (i.e., packet size or rate). In theory, the network could use frame error rate (FER) information fed back from the data user to make rate

adjustments, but that would not allow timely rate adjustments because relatively long periods of time, e.g., a hundred or more received frames, are required to develop statistically accurate FER information.

[0004] Overall network performance and efficiency suffer because of the inability to intelligently adjust F-SCH data rates. That is, where the data rate of a given F-SCH is too high given the current radio conditions of the data user the channel is assigned to, the effective data rate of the channel is lowered because of the high incidence of reception errors and the transmit power allocated for the inappropriately high data rate is at least partially wasted. Of course, the converse is true, wherein the network misses opportunities to make timely increases in F-SCH data rates responsive to improving radio conditions for particular data users.

[0005] These circumstances are not limited to IS-2000 networks. Indeed, the potential for such inefficiencies arise in any communication network wherein rate-adjustable channels are assigned to users and managed without benefit of direct rate control feedback from the users.

SUMMARY OF THE INVENTION

[0006] The present invention comprises a method and apparatus to provide communication channel rate adaptation in a wireless communication network, such as in cdma2000 or Wideband CDMA (WCDMA) cellular communication networks. In an exemplary embodiment, the present invention comprises a method of channel data rate adaptation in a wireless communication network based on setting a data rate for a communication channel to be used for transmitting data to a remote receiver at a variable transmit power that is controlled upward and downward by the remote receiver as needed to achieve a desired received data quality at the remote receiver, monitoring transmit power information for the communication channel as an indication of current

radio conditions at the remote receiver, and changing the data rate for the communication channel based on the transmit power information.

[0007] In an exemplary embodiment of the above method, the communication channel is a rate-adjustable data channel, such as a F-SCH transmitted from a radio base station to a remote mobile station. The radio base station has knowledge of the transmit power being used to transmit data to the mobile station on the channel, and thus can monitor that transmit power as an indication of radio conditions at the mobile station. For example, where the transmit power is on average close to an upper power limit set for the channel, the radio base station infers that the current data rate of the channel is too high. Conversely, where the transmit power is on average close to a lower power limit set for the channel the radio base station infers that the current data rate of the channel is too low. In the former case, the radio base station initiates a downward rate change for the channel and, in the latter case it initiates an upward rate change for the channel.

[0008] More generally, the radio base station compares the transmit power information to rate adjustment thresholds that trigger up or down rate adjustments if the thresholds are met or exceeded. For example, the comparison of average transmit power to a threshold set relative to a power requirement associated with a higher data rate may trigger an upward rate adjustment if the comparison indicates that there is sufficient power margin for reliable operation at the higher data rate. Thus, the upward rate adjustment threshold may be set in relation to the upper power bound of the next higher data rate.

[0009] An exemplary radio base station comprises transmitter circuits to transmit radio signals on one or more forward link communication channels to mobile stations; and a forward link processing circuit to control the transmitter circuits. Exemplary forward link processing circuits are configured to set a data rate for a communication

channel to be used for transmitting data to a mobile station at a variable transmit power that is controlled upward and downward by the mobile station as needed to achieve a desired received data quality at the mobile station. These circuits include a rate adaptor circuit that is configured to monitor transmit power information for the communication channel as an indication of current radio conditions at the mobile station, and change the data rate for the communication channel based on the transmit power information.

[0010] By way of non-limiting examples, the transmit power information monitored by the radio base station for a given communication channel of interest may comprise an average of the actual transmit power being used to transmit data on the channel. For example, the base station may filter (smooth) power values over a given number of transmit frames, and it may apply different filters such that it makes downward rate adjustments more quickly than it makes upward rate adjustments. Alternatively or additionally, the base station may monitor forward link power control commands (bits) from the mobile station. For example, if a large percentage of those commands are up commands, the base station infers that the channel data rate is too high for current radio conditions at the mobile station. Conversely, if a large percentage of the commands are down commands, it infers that the mobile station could support a higher data rate.

[0011] While the present invention may have particular applicability to rate adaptation for forward link supplemental channels in cdma2000 networks, it is not limited to such networks. Further, those skilled in the art will recognize additional features and advantages in light of the following detailed discussion and the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Fig. 1 is a diagram of an exemplary wireless communication network according to an embodiment of the present invention.

Fig. 2 is a diagram of an exemplary radio base station.

Fig. 3 is a diagram of typical per-frame transmit power variations for a given communication channel of interest.

Fig. 4 is diagram of typical forward link power control commands as might be returned to a network radio base station from a particular mobile station.

Fig. 5 is a diagram of exemplary filters to transmit power information for rate adaptation monitoring.

Fig. 6 is a diagram of first and second filtered values illustrating the use of different, e.g., fast and slow, filter time constants for rate adaptation monitoring.

Fig. 7 is a diagram of exemplary processing logic for rate adaptation according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0013] Fig. 1 illustrates an exemplary wireless communication network 10 that generally may be configured according to known communication standards. For example, network 10 may comprise a cdma2000 network based on IS-2000/2001 standards. It should be understood that network 10 also could be configured according to other standards as needed or desired, including Wideband (WCDMA) standards, for example.

[0014] Regardless, network 10 comprises a Radio Access Network (RAN) 12 that supports wireless communication between mobile stations 14 and one or more Public Data Networks (PDNs) 16, such as the Internet, based on its Radio-Packet (RP) interface with Packet Switched Core Network (PSCN) 18. RAN 12 also may be configured to carry voice and other circuit-switched communication traffic between the mobile stations 14 and users of the Public Switched Telephone Network (PSTN) 20 based on its traffic and signaling interfaces with Circuit-Switched Core Network (CSCN)

22, which typically includes a Mobile Switching Center (MSC) 24 to handle voice call setup/teardown, etc.

[0015] In any case, an exemplary RAN 12 comprises one or more Base Station Controllers (BSCs) 30, each one associated with one or more Radio Base Stations (RBSs) 32. A Packet Control Function (PCF) 34 is associated (or integrated) with each BSC 30, and provides an interface to a Packet Data Serving Node (PDSN) 38 in the PSCN 18. PDSN 38 carries packet data traffic for mobile stations 16, and may be coupled through a local (private) IP network 40 to a gateway router 42 that provides access to the Internet at large, or to one or more other PDNs 16. The PSCN 18 may comprise various other entities 44, such as Home Agents and Foreign Agents to manage packet data mobility functions.

[0016] While potentially helpful in terms of understanding exemplary network operations in a broad sense, details of the CSCN 16 and PSCN 18 are not required for understanding the present invention, which generally concerns operations and equipment in RAN 12, and, in particular, concerns RBSs 32 and BSCs 30.

[0017] Turning, then, to exemplary details for an RBS 32 configured according to one or more embodiments of the present invention, Fig. 2 illustrates that RBS 32 functionally comprises BSC interface circuits 50, reverse link signal processing circuits 52 and associated receiver circuits 54, forward link signal processing circuits 56 and associated transmitter circuits 58. Forward link signal processing circuits 56 comprise a rate adaptor circuit 60 that includes a processing circuit 62 and one or more monitoring/filtering circuits 64, which may be integrated with the processing circuit 62. A forward link (transmit) power control circuit 66 may be associated with, or included in, the forward link signal processing circuits 56.

[0018] These various functional elements can be implemented in hardware, software, or both, and the exemplary RBS 32 includes one or more microprocessor

circuits, such as Digital Signal Processors (DSPs), and associated supporting circuits, such as memory, etc. As such, in an exemplary embodiment, the present invention, including rate adapator circuit 60, is implemented at least in part as a computer program stored in memory for execution in one or more RBS microprocessor circuits.

[0019] RBS 32 supports wireless communication to and from individual ones of the mobile stations 14 by transmitting signals to the mobile stations 14 using one or more forward link channels and receiving signals from the mobile stations 14 using one or more reverse link channels. In an exemplary embodiment, each mobile station 14 is served using one or more dedicated (mobile-specific) forward and reverse link channels.

[0020] Power control loops on the forward and reverse links operate to maintain the forward and reverse link channel transmit powers substantially at, but preferably not higher than, the levels needed to achieve a desired received signal level quality at both the RBS 32 and at the mobile stations 14. For example, for a particular mobile station 14, the RBS 32 sends reverse link power control commands at a defined rate to the mobile station 14, and mobile station 14 moves its transmit power up or down according to the commands. Thus, if the RBS 32 is receiving the mobile station's reverse link signals below a targeted signal-to-noise ratio, it sends up commands to the mobile station and, conversely, if it is receiving the mobile station's signal above the targeted signal quality, it sends down commands. According to this scheme, then, the transmit power from the mobile station 14 moves up and down as needed to achieve the desired signal quality at the RBS 32.

[0021] Similarly, the mobile station 14 sends forward link power control commands, e.g., Power Control Bits or PCBs, to the RBS 32 that command the RBS 32 to increase or decrease its transmit power to the mobile station 14 according to a desired received signal quality at the mobile station 14. For example, the mobile station 14 may compute a target received signal quality and then send up or down power commands to RBS 32

as needed to maintain the received signal quality at or around that target. Along with this, the mobile station 14 may monitor a Frame Error Rate (FER) for data received from the RBS 32 and may raise or lower the received signal quality target depending on whether the FER is high or low.

[0022] Link power control of this nature generally is well understood by those skilled in the art, however, according to the present invention, transmit power information associated with such closed loop power control is used to make channel data rate adaptations. For example, in the context of F-SCHs in cdma2000 networks, the present invention may be used to provide dynamic rate adaptation for a given F-SCH based on the transmit power of that F-SCH. More broadly, the present invention provides a relatively fast, e.g., per transmit frame or better, methodology for performing channel rate adaptation based on transmit power information. According to a broad embodiment, a relatively high transmit power indicates that the channel data rate should be adapted downward and a relatively low transmit power indicates that the channel data rate should be adapted upward. As such, the present invention can be applied to essentially any communication channel that is rate adjustable. Such application may be particular beneficial where the channel in question lacks an explicit rate control feedback mechanism keyed to received signal quality at the remote receiver.

[0023] As an example, Fig. 3 illustrates the changing transmit powers used by RBS 32 for the transmission of data to a particular mobile station 14 on a F-SCH assigned to that mobile station 14. In general, the transmit power required for a F-SCH depends on its configured data rate, the path loss on the forward link, and the interference at the remote receiver, i.e., at the targeted mobile station 14. Broadly, then, the required transmit power is a function of channel data rate and overall radio conditions. As shown in the illustration, the required transmit power varies over time—four frames are illustrated—as a function of changing radio conditions.

[0024] Fig. 4 illustrates a typical stream of up/down power control commands as might be sent by the mobile station 14 to the RBS 32 to control the forward link transmission power used by the RBS 32 to transmit to the mobile station 14. For example, the mobile station 14 commands the RBS 32 to increase its transmit power by sending up commands if the mobile station is experiencing too many errors in the data it receives from RBS 32. Conversely, as explained above, mobile station 14 sends down power control commands to RBS 32 if the mobile station 14 is receiving data at an error rate lower than the target. Of course, in normal operation, with fast fading and other dynamic variations in radio conditions, the power control commands streamed back to the RBS 32 from the mobile station 14 comprise an ever changing mix of up and down power control commands. However, in general, the commands are predominantly up commands where the mobile station 14 is experiencing excessive received data errors, and the commands are predominantly down commands where the mobile station is experiencing relatively few data errors.

[0025] Fig. 5 illustrates an exemplary approach to transmit power information monitoring that may be adopted by the RBS 32 of Fig. 3 for rate adaptation of a particular forward link channel of interest, wherein the actual transmit power being used for the channel is monitored, or the incoming power control commands from the targeted mobile station are monitored. Thus, in a first exemplary embodiment, the rate adaptor circuit 60 dynamically adapts the data rate of a particular F-SCH up or down based on monitoring the actual transmit power being used to transmit on the channel. Alternatively, the rate adaptor circuit 60 dynamically adapts the rate based on the power control commands returned by the mobile station 14.

[0026] In either case, the monitor/filter circuits 64 may comprise one or more filter circuits 72. In an exemplary embodiment, the raw power data (either values corresponding to the transmit power or to the incoming stream of power control

commands) is routed into a first filter 72-1 that is configured with a first filter time constant to effect a desired amount of filtering. Optionally, the data also is routed into a second filter 72-2 that is configured with a second filter time constant to effect a desired amount of smoothing. In one configuration, the first filter time constant is set less than the second filter time constant such that the first filtered values output by filter 72-1 more rapidly track changes in the pre-filtered data, while the second filtered values output by filter 72-2 exhibit a greater degree of smoothing.

[0027] It may be desirable, for example, to make downward rate adjustments more quickly than upward rate adjustments. Thus, downward rate adjustment decisions may be made based on monitoring the first filtered values relative to defined thresholds, and upward rate adjustments may be made based on monitoring the second filtered values relative to the same or different thresholds.

[0028] Fig. 6 illustrates such an embodiment, and one sees that that the second filtered values exhibit greater smoothing, i.e., a longer filter time constant, than the first filtered values. Further, one sees that both sets of filtered values change over time relative to defined upper and lower limits. If the filtered values are derived from the actual channel transmit power, then the upper and lower limits can be set at the minimum and maximum powers defined for the channel. Transmit power control circuits 66 that provide forward link transmit power for the individual communication channels can be configured to provide the rate adaptor circuit 60 with the transmit power information for any number of channels subject to rate adaptation according to the present invention.

[0029] If the filtered values used for rate adaptation are derived from the mobile station's power control commands, then the upper and lower limits can be set at percentage or fractional values. For example, if a "0" defines a down power command and a "1" defines an up power command, then the filtered values will range from a

minimum of zero (all "0s" received) to a maximum of one (all "1s" received). A value of about 0.5 would represent a more or less even mix of up and down commands. Thus, the lower limit could be set at 0.25 and the upper limit could be set at 0.75. The lower limit would be reached if the larger percentage of power control commands incoming from the mobile station 14 were down commands, and the upper limit would be reached if the larger percentage were up commands. Of course, those skilled in the art will recognize that these are merely example limits that can be changed as needed or desired.

[0030] Additionally, those skilled in the art will recognize the opportunity to vary the filtering process as needed or desired. In an exemplary embodiment, the filter characteristics may be configured to achieve a desired averaging response. Filter performance may be adjusted by configuring the number of transmit frames over which the transmit information is developed, i.e., the number of transmit frames over which the average is determined. In an exemplary embodiment, new transmit power information is available per 20 ms frame. Similarly, in embodiments that derive transmit power information from the incoming power control commands, filter performance can be adjusted by changing the number of commands that are averaged. Incoming power control commands are received at up to 800 Hz (every 1.25 ms), and averaging operations can be configured to balance smoothness with responsiveness.

[0031] Further, regardless of filter configuration, it may be desirable to "reset" filtering after a rate increase or decrease. Such filter resetting helps prevent false re-triggering of the rate adaption method immediately after a rate change. As an exemple, the method may include resetting the transmit power information to half the last filtered power value determined prior to a rate decrease, or to double the last value determined prior to a rate increase. Of course, other reset values can be used and, if separate filters

are used for triggering rate increases and decreases, reset operations may be tailored to each individual filter.

[0032] Regardless, Fig. 7 illustrates exemplary rate adaptation processing. In general, processing comprises ongoing transmit power information monitoring (Step 100) wherein the desired transmit power information is filtered (using one or more filters as needed or desired) for use in rate adaptation. Rate adaptation may be run at essentially any rate desired, depending on the availability of transmit power information. For example, in cdma2000 networks, frame transmit power data is available on a per frame rate, e.g., every twenty milliseconds. Thus, twenty milliseconds represent an exemplary rate adjustment interval for F-SCH rate adaptation. Power control commands returned from the mobile station 14 are available at up to 800 Hz, and even with filtering the use of these power control commands supports a per-frame or better rate adaptation interval.

[0033] Thus, if it is time for rate adaptation for a given channel or channels of interest (Step 102), the rate adaptor 60 compares the first filtered value against the upper limit (Step 104). If the first filtered value is above the upper limit (Step 106), rate adaptor 60 initiates a downward rate adjustment (Step 108). If not, the rate adaptor 60 compares the second filtered value to the lower limit (Step 110). If the second filtered value is below the lower limit, the rate adaptor 60 initiates an upward rate adjustment (Step 112). If the first and second values are between the upper and lower limits, no rate adjustments are made. Processing ends with respect to the current rate adjustment interval, but it should be understood that monitoring can continue and that the above process can be repeated at the desired adjustment interval or as needed.

[0034] As an exemplary alternative to comparing filtered transmit power values to a lower power bound set relative to a current channel data rate, the rate adaptor 60 generally may compare the filtered value to a threshold derived from the power

requirements of a higher data rate. For example, the filtered value may be compared to a threshold set relative to an upper power bound associated with the next higher data rate. By making that comparison, the rate adaptor 60 ensures that a sufficient power margin will exist to maintain the integrity of the call at the contemplated higher rate in consideration of normal power fluctuations. As an example, suppose that the current channel is at a rate 4x and the next higher rate is 8x. In determining whether to move from 4x to 8x, the rate adaptor 60 compares the filtered value to threshold associated with the maximum power defined for the 8x rate to determine whether to initiate the rate increase.

[0035] More generally, the rate adaptor 60 can determine whether to increase the data rate by making the comparison to a threshold that will ensure sufficient power adjustment range to maintain radio link quality at the contemplated higher rate. The comparison threshold thus should be set relative to the upper power bound defined for the contemplated data rate to allow for reasonable margin.

[0036] In initiating a rate adjustment, the rate adaptor circuit 60 may send a rate adjustment message to the BSC 30, or otherwise signal to the BSC 30 that a rate adjustment is needed. The control/interface circuits 70 of BSC 30 can be configured to respond to such signaling by sending an Extended Supplemental Channel Assignment Message (ESCAM) to the mobile station 14 to cancel the previous rate assignment of the mobile station's F-SCH and to inform the RBS 32 of the rate change so that it can reconfigure the rate accordingly..

[0037] Thus, in an exemplary embodiment directed to F-SCH rate adaptation in a cdma2000 network, RBS 32 can be configured to perform rate adaptation on any number of F-SCHs being supported by the RBS 32. For any of these channels, the RBS 32 initiates downward rate adjustments as needed in response to determining that the transmit power information for that channel indicates that a relatively higher power is

required to support the current data rate of the channel. Conversely, the RBS 32 initiates upward rate adjustments as needed in response to determining that a relatively lower power is required to support the current data rate of the channel, or that the current average power is such that the next higher data rate could be supported with sufficient power margin. So configured, the RBS 32 uses transmit power information to infer whether a particular mobile station 14 is in relatively good or relatively bad radio conditions, and to make the correspondingly appropriate rate adaptation.

[0038] As noted, the present invention has particular applicability to F-SCH rate adaptation in cdma2000 networks, but those skilled in the art will recognize that the present invention can be applied to essentially any type of channel in any type of network where adaptive rate control is desired, and where transmit power information for the channel varies as a function of received signal quality at the targeted receiver. As such, the present invention is not limited by the foregoing discussion, but rather is limited only by the following claims and their reasonable equivalents.